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U. S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

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Laboratory Evaluation of Frost Heave Characteristics of a Slag - Fly Ash - Lime Base-Course Mixture

by C. W. Kaplar

U. S. ARMY COLD REGIONS RESEARCH
AND ENGINEERING LABORATORY
Hanover, New Hampshire

PREFACE

The studies reported herein were carried out under the over-all direction of the Civil Engineering Branch, Engineering Division, Military Construction, Office, Chief of Engineers, Department of the Army, of which Mr. Thomas B. Pringle is Chief and Mr. Frank B. Hennion is Assistant Chief. The tests were conducted by the Arctic Construction and Frost Effects Laboratory,* U. S. Army Engineer Division, New England, Waltham, Massachusetts (Mr. Kenneth A. Linell, Chief).

The tests were made as a result of a request for information by the North Central Division of the Corps of Engineers which furnished the necessary ingredients and the supplier's recommended mix proportions.

* Now a part of USA CRREL

Manuscript received 19 April 1962

CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

Sixteen specimens of a slag-fly ash-lime base-course mixture were tested for frost susceptibility in the laboratory. The mixture consisted of 66% slag, 30% fly ash and 4% lime, by weight. Base courses of this type are being used in certain parts of the country in competition with conventional base-course materials.

The slag-fly ash-lime base-course mixture used in these tests consisted of minus ⅜-in. material with 30% finer by weight than No. 200 mesh sieve and 18% finer than 0.02 mm. According to the Corps of Engineers' criteria for base courses, this gradation is classified as frost-susceptible.

Different methods of cure treatment were tried and the effect of aging (up to 12 months duration) on frost-susceptibility was observed on 6-in. diam, 6-in. high specimens. Cure treatment prior to freezing consisted of: 1) curing in oven at 140F for 7 days; 2) "moist curing" in wet sand from 1½ to 12½ months; 3) complete immersion in water for 2 weeks followed by "curing" in wet sand up to 12½ months; and 4) no curing. Some specimens were subjected to 5 or 6 cycles of freezing and others to 10 cycles. Specimens were generally frozen uniaxially from top to bottom at a rate of approximately ½-in. per day.

Test results showed that oven-cured specimens heaved insignificantly even after 10 cycles of slow freezing in an open-system test, while non-cured specimens heaved about 15% during a single freezing and were classified to be of low frost susceptibility. In accordance with adopted criteria, based on average rate of heave in mm/day, most moist-cured and soaked specimens were classified as negligible frost-susceptible although a few approached or were classified as very low frost-susceptible.

Specimens cured only in moist sand performed significantly better on the whole than those first submerged in water and then moist-cured. On "moist-cured only" specimens, heaving decreased with increase in curing time. The maximum measured heave of any of the cured specimens, soaked or otherwise, during any one freezing cycle was approximately 0.2 in. and about 3.3%.

LABORATORY EVALUATION OF FROST HEAVE CHARACTERISTICS OF A SLAG-FLY ASH-LIME BASE-COURSE MIXTURE

by

Chester W. Kaplar

INTRODUCTION

In many parts of the country, natural sources of good, clean base-course material are becoming rapidly depleted. In metropolitan areas, it has become necessary to import materials from considerable distance or use a plant-processed product. In any event, costs run high and are continuously climbing. Highway officials and engineers are constantly searching to achieve economies wherever possible whether in materials or design. The Division and District offices of the U. S. Army Corps of Engineers are among the foremost in searching for improved and economical approaches to all engineering problems.

In industry also, constant efforts are being made to achieve economy in both production and operating costs. One of the major problems faced by big industry is the utilization of large quantities of so-called "waste" or byproducts accumulated in a manufacturing or industrial process. In some modern power plants, large quantities of boiler slag and fly ash are byproducts which must be either wasted or disposed of in the most advantageous manner. Boiler slag is formed by the fusion of the incombustible ingredients of soft coal dust during combustion. It is collected beneath the boiler grates. Fly ash is the fine residue remaining in the smoke after combustion is completed. It is mostly silica and alumina and thus is classed as a pozzolan. The American Society for Testing Materials defines a pozzolan as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."

Fly ash is a man-made pozzolan. It was originally removed by electrostatic precipitation in the flues of chimneys to avoid air polution but later was found to be an effective pozzolan. Slag has been frequently used for fill or ballast. In recent years a number of uses have been found for the fly ash, one of them as a beneficial ingredient of portland cement concrete.

The cementing properties of volcanic ash were recognized and used by the early Romans over 2000 years ago. The Romans discovered that a volcanic ash found in beds near Naples, when mixed with lime, would produce a water-tight cement which would set up under water. This type of cement was used by the Romans as early as 312 B.C. and it was subsequently used in many engineering structures throughout the Roman empire. Cements thus made, from natural volcanic ash, are known as "pozzuolana", a name derived from the location of early beds in Italy at Pozzuoli, near Naples. Pozzuolanic cements are still being used in Italy and other countries where similar deposits of volcanic ash are available. The word "pozzolanic" is used today, inaccurately according to some, to describe a mixture of blast furnace slag, fly ash, and lime because of similarity of the ingredients.

In the Chicago area and other large cities, such artificial or man-made pozzolanic mixtures have been used for a number of years by city, county, and local transit authorities as base courses in a number of parking areas and roadbeds because of its availability and structural advantage over conventional base-course materials. Typical mixtures used consist generally of the following proportions: Slag 66 - 72%, fly ash 24 - 30%, and lime 4 - 5%. Available data indicate that the mixture may set up in a period of several months to about 2000 psi compressive strength and 400 psi flexural strength (Hallon and Mark, 1960). Some available rapid freeze-thaw data show 1.9%

loss after 12 cycles, with no brushing of the specimens. On a cost basis, this material compares very favorably with graded crushed stone, costing about $2.00 per ton at the plant (Chicago area).

The tests reported herein were conducted by the Arctic Construction and Frost Effects Laboratory* of the U. S. Army Engineer Division, New England, Waltham, Massachusetts. The tests were made as a result of a request for information by the North Central Division of the Corps of Engineers, which furnished the necessary ingredients and the supplier's recommended mix proportions.

The Corps' interest in this material stems strictly from a utilitarian viewpoint. However, the requirements of the Corps for base-course materials are stringent from the standpoint of stability and bearing capacity. The Corps' requirements specify that the material should be non-frost-susceptible when used in climatic areas where freezing temperatures occur. The frost susceptibility of graded granular materials is controlled by specifying that the gradation contain not more than 3% by weight of grains finer than 0.02 mm size. The combined gradation of the slag-fly ash-lime mixture used in these studies in proportion of 66, 30, 4% respectively contains about 30% passing the No. 200 mesh sieve and 18% finer than the 0.02 mm size.

The laboratory tests conducted by the Arctic Construction and Frost Effects Laboratory were designed to evaluate the frost susceptibility of the mixture as a base-course material, not as a cement concrete. However, since the mixture under consideration has cementitious properties, its behavior during freezing would undoubtedly be affected by the degree of cementation achieved at the time of freezing. The degree of cementation and strength that can be achieved is usually dependent on the method and duration of curing. A high degree of cementation and strength in this material has been achieved by heat curing for 7 days at 140F. Obviously this cannot be readily accomplished on the roadbed. Whatever curing occurs must occur under natural conditions existing at the particular location. The material is likely to be exposed to extreme wetness or dryness, depending on the weather. To properly evaluate frost susceptibility the laboratory tests were designed to take such field-curing conditions into consideration. Three different methods of curing treatment were used and, in addition, two specimens were prepared and frozen within a few days of preparation after no curing treatment except saturation under vacuum in accordance with adopted test procedures.

Other specimens were subjected to one of the three methods of curing treatment for varying periods of time. It was felt that the frost-susceptibility evaluation should consider the effect of elapsed time between placing of the material and the first freeze. If freezing behavior of the mixture should be sensitive to curing time, then a pavement base constructed in April and subjected to natural freezing in late November or December would be expected to react somewhat differently from one constructed in early November.

Another factor to be considered in the evaluation was the possible effect of several freeze-thaw cycles such as might occur in a pavement in most areas of the temperate zone during a single freezing season. In many areas of the United States, the top foot of pavement would probably be subjected to several cycles of freezing and thawing during a winter.

The effectiveness of a cemented material in resisting ice lens formation also depends upon its imperviousness and the quality of the cementing bonds. Any breakdown in the bonding such as might be produced by a crack or plane of separation during freezing might make the material more porous and thus provide more channels for passage and retention of water, which upon further freezing expands and produces more separation and deterioration. If the bonds are sufficiently strong and the material relatively impervious, deterioration due to frost action will be resisted. Should a cemented

*Now merged with the U. S. Army Snow Ice and Permafrost Research Establishment to form the U. S. Army Cold Regions Research and Engineering Laboratory located at Hanover, New Hampshire.

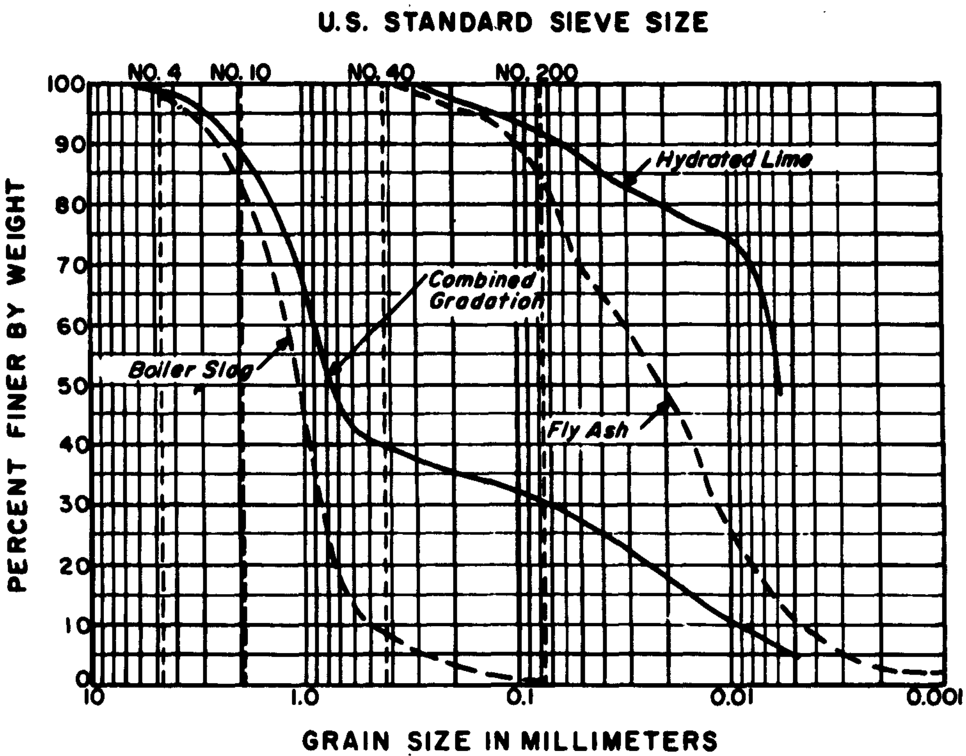


Figure 1. Grain size distribution of combined mixture and components.

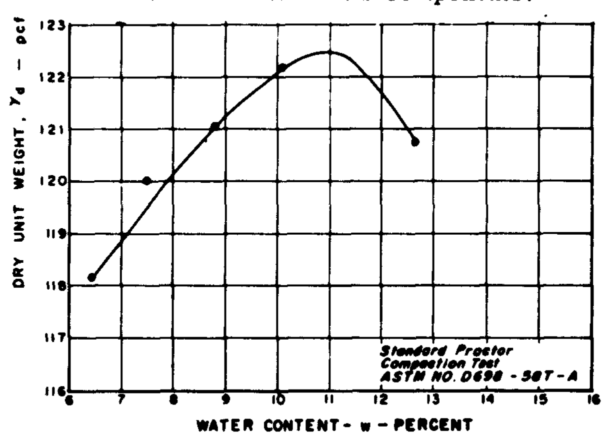


Figure 2. Relationship between dry unit weight and molding water content.

material such as is being considered in this study deteriorate in time, irrespective of cause, to a condition approaching its original gradation prior to cementation, the stability of the base course would be greatly affected by the change, as well as its susceptibility to frost action under adverse conditions of moisture and temperature.

LABORATORY FREEZING TESTS FOR FROST SUSCEPTIBILITY

Preparation of specimens

Sixteen specimens, 6 in. in diameter and 6 in. high, were prepared by dry mixing the ingredients in the following proportions by weight: slag 66%, fly ash 30%, hydrated lime 4%. The gradation of the ingredients and the combined gradation of the mixture are shown in Figure 1. The pertinent physical properties of the materials used are tabulated in Table 1. Each specimen was compacted to approximately 100% of the maximum dry unit weight as determined by the standard Proctor method (AASHO designation T99-57, Method A) and 10.5% moisture content. A compaction curve relating molding water content and dry unit weight is shown in Figure 2. All specimens were compacted in a slightly tapered steel molding cylinder having a $\frac{1}{4}$-in. larger diameter at the top, in four equal layers, using a 5.5 lb compaction hammer, 12-in. drop and 25 blows per layer. The specimens were then removed from the molding cylinder and placed in similarly tapered Lucite cylinders.

Curing treatment

The test specimens were divided into four groups depending upon the method of curing. The groups and specimens are identified in Table 2.

After curing each specimen was prepared for freezing tests according to ACFEL standard procedure.

Freezing tests

Specimens were frozen in pairs, each pair in a separate freezing cabinet. One specimen of each pair was instrumented with thermocouples imbedded 1-in. apart along the longitudinal centerline to measure the penetration of freezing temperature. The freezing cabinets, equipment, methods and procedures used have been described in detail in two previous publications (ACFEL, 1958; Linell and Kaplar, 1959).

All specimens were frozen uniaxially from top to bottom at a rate of approximately $\frac{1}{4}$-in. per day during the first freezing cycle. Subsequently all specimens subjected to repetitions of freezing were frozen at a rate of $\frac{1}{2}$ in. per day to hasten completion of the studies. Free water was provided at the bottom of all specimens during each freezing period. Originally it was planned to apply only 5 or 6 freeze-thaw cycles to all specimens except the non-cured specimens P-21 and P-22, which were frozen only once. After the tests consisting of 5 and 6 freeze cycles were completed on the first pairs tested (curing period less than 6 weeks) from groups A, B, and C, it was decided to increase the repetitive freezings to 10 cycles for one specimen of each pair scheduled to be tested subsequently in groups B and C (after longer curing or aging periods).

Frost-heave and thaw-settlement readings were recorded daily during each freezing and thawing. After final freezing, the frozen specimens were split longitudinally into two parts for visual observation of ice lens formation and determination of water content distribution. The specimens were thawed by simply turning off the refrigeration, opening the top cover of the freezing cabinet and exposing both tops and bottoms of the specimens to the ambient 38F cold room temperature around the cabinets. Thawing was generally achieved in less than 24 hr.

Some swelling to various degrees was observed in all of the "cured" specimens during curing. The two oven-cured specimens in group A increased in length by approximately 0.025 in. The increase in length of specimens in group B ranged from 0.004 to 0.045 in. with an average increase of approximately 0.02 in. The soaked specimens in group C increased in length by an average of 0.14 in. The two noncured specimens in group D shrunk 0.068 to 0.047 in. respectively during the first day of freezing, probably as a result of the tensile stress developed in the pore water when freezing began.

Table 1. Physical properties of slag-fly ash-lime base-course mixture.

Composition		Compaction data* of mixture		Specific gravity	
Materials mixed	Proportion by weight (%)	Maximum dry unit weight (pcf)	Optimum moisture content (%)	Each ingredient	Average of mixture
Slag	66			3.04	
Fly ash	30	122.5	11.0	2.55	2.88
Hydrated lime	4			2.75	

* By the standard Proctor method (AASHO Designation T99-57, Method A).

Table 2. Methods of curing.

Group designation	Specimen number	
A	P-1 P-2	Placed in metal container, sealed and placed in oven at 140F for 7 days.
B	P-9 P-10	Placed in moist sand, top exposed to room temperature and humidity for 2 weeks. Top covered, specimens cured for 1 month.
	P-11 P-12	Same method as P-9 and P-10 except cured for 4 months.
	P-13 P-14	Same method as P-9 and P-10 except cured for 12 months.
C	P-15 P-16	Buried in moist sand, top exposed to room temperature and humidity for 3 days, specimen placed in Lucite cylinder and then submerged in water with porous stones on top and bottom for 2 weeks. Removed from water and placed in moist sand inside Lucite cylinders with porous stones top and bottom for 1 month, all within covered container.
	P-17 P-18	Same method as P-15 and P-16 except cured for 4 months.
	P-19 P-20	Same method as P-15 and P-16 except cured for 12 months.
D	P-21 P-22	Noncured. Specimens saturated under vacuum and freezing started within 5 days.

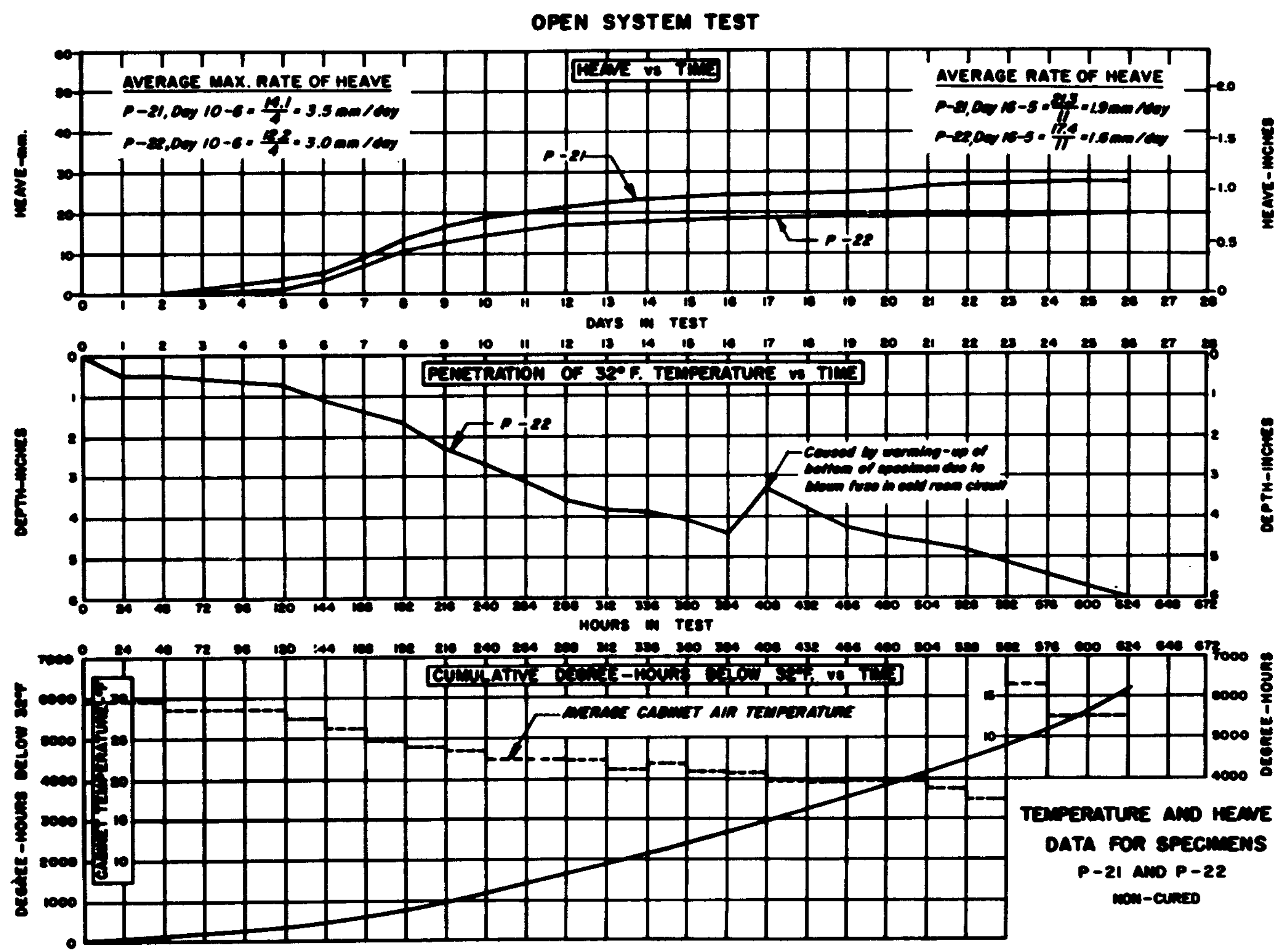

OPEN SYSTEM TEST
HEAVE vs TIME
AVERAGE MAX. RATE OF HEAVE
P-21, Day 10-6 = 14.1/4 = 3.5 mm/day
P-22, Day 10-6 = 12.2/4 = 3.0 mm/day
AVERAGE RATE OF HEAVE
P-21, Day 16-5 = 21.3/11 = 1.9 mm/day
P-22, Day 16-5 = 17.4/11 = 1.6 mm/day
P-21
P-22
HEAVE-mm.
HEAVE-INCHES
DAYS IN TEST
PENETRATION OF 32° F. TEMPERATURE vs TIME
P-22
Caused by warming-up of bottom of specimen due to blown fuse in cold room circuit
DEPTH-INCHES
HOURS IN TEST
CUMULATIVE DEGREE-HOURS BELOW 32°F. vs TIME
AVERAGE CABINET AIR TEMPERATURE
CABINET TEMPERATURE-°F
DEGREE-HOURS BELOW 32°F
DEGREE-HOURS
TEMPERATURE AND HEAVE
DATA FOR SPECIMENS
P-21 AND P-22
NON-CURED

Figure 3.

Test results

A summary tabulation of specimen preparation and freezing test data is presented in Tables 3 and 4. Figure 3 shows the heave and temperature penetration data of the two "noncured" specimens P-21 and P-22, which were frozen at approximately $\frac{1}{4}$ in. per day in a standard ACFEL frost susceptibility test (one freezing only). The heave and thaw settlement data for all other specimens subjected to several cycles of freezing and thawing have been plotted in the form of bar graphs in Figures 4, 6 and 8 showing the total heaving and amount of settlement for each cycle. The total cumulative heave (heaving less thaw-settlement) remaining after each freeze-thaw cycle has been plotted for each specimen in Figures 5, 7 and 9.

The daily heave plots for the cured specimens, groups A, B, and C, were in most cases very similar in form to the heave plots for the noncured specimens (Fig. 3) except for order of magnitude. The greatest portion of the heaving occurred during the early part of the test. Most heave plots typically showed a fairly steep initial heave rate and a gradual flattening out as shown in Figure 3. This is probably due to restraint caused by side friction between specimen and walls of container even though the container was tapered with larger diameter at the top. Some swelling was observed in nearly all specimens during curing, as indicated in Table 3. It has also been observed that generally more side friction develops in specimens which exhibit negligible or very low frost heaving characteristics because of lateral expansion during freezing. In soils with more pronounced frost-susceptibility characteristics heaving at any plane raises all the soil above that plane to a position of greater diameter in the tapered cylinder, thus minimizing frictional restraint.

The vertical water content distribution prior to and after completion of final freeze is plotted for all specimens in Figures 10, 11 and 12.

Photographs of sections of all frozen specimens are shown in Figure 13. Visual observations of appearance of each specimen after final freeze are tabulated in Table 5.

Discussion of results

Specimens P-1 and P-2, which were oven cured for 7 days at 140F prior to freezing, were the least affected even after 5 cycles of freezing and thawing. The average cumulative heave of these two specimens was less than 0.025 in. after 5 freezings. The test results obtained for each freeze-thaw cycle for these two specimens are plotted in Figure 4 in the form of a bar graph. The measured heave at the completion of each freezing is plotted above the zero reference line while the settlement during thaw from the heaved position is plotted below the reference line to permit comparison of all heave settlement data. Figure 5 presents the total cumulative heave of each specimen versus freeze-thaw cycles.

Examination of the data obtained from these tests shows that "noncured" specimens P-21 and P-22 heaved the greatest amount, approximately 1 in. The average rate of heave computed over a continuous period of 11 days when heaving and frost penetration were fairly uniform (see Fig. 3) was 1.9 and 1.6 mm/day, respectively. The average maximum rate of heave was much greater, being 3.5 and 3.0 mm/day, over a consecutive period of 4 days. According to criteria used by ACFEL the frost susceptibility of a "noncured" mixture of slag-fly ash-lim is classified as low but approaching medium.

The following scale for classification of the degree of frost susceptibility of a soil tested using procedure described in this paper, based on the average rate of heave over several consecutive days, had been adopted for rates of freezing between $\frac{1}{4}$ and $\frac{3}{4}$ in. per day.

Average rate of heave (mm/day)	Frost-susceptibility classification
0 - 0.5	Negligible
0.5 - 1.0	Very low
1.0 - 2.0	Low
2.0 - 4.0	Medium
4.0 - 8.0	High
Greater than 8.0	Very high

Table 3. Specimen preparation for slag-fly ash-lime base-course mixture. All specimens molded at 10.5% water content.

ACFEL Specimen No.	Molded height (in.)	Height after curing* (in.)	Increase in height (in.)	Dry unit weight before freezing (pcf)	Degree of compaction† (%)	Void ratio e
Group A						
P-1	5.873	5.902	.029	122.9	100	0.452
P-2	5.875	5.897	.022	123.0	100	0.451
Group B						
P-9	5.99	5.994	.004	120.8	99	0.477
P-10	6.00	6.009	.009	120.7	99	0.479
P-11	5.960	5.994	.034	121.2	99	0.472
P-12	6.000	6.01	.01	121.2	99	0.472
P-13	5.99	6.004	.01	120.3	98	0.483
P-14	5.98	6.025	.05	119.8	98	0.490
Group C						
P-15	5.98	6.114	0.13	118.9	97	0.501
P-16	5.99	6.154	0.16	118.2	97	0.510
P-17	5.98	6.125	0.15	118.7	97	0.503
P-18	5.98	6.118	0.14	118.8	97	0.502
P-19	6.00	6.144	0.14	118.3	97	0.509
P-20	5.99	6.11	0.12	118.9	97	0.501
Group D						
P-21	5.94	-	**	122.3	100	0.459
P-22	5.93	-	**	122.4	100	0.458

* Curing time for each specimen presented in Table 4.
† Prior to freezing.
** Both specimens shrunk in height an average of 0.058 in. during first day in freezing cabinet.

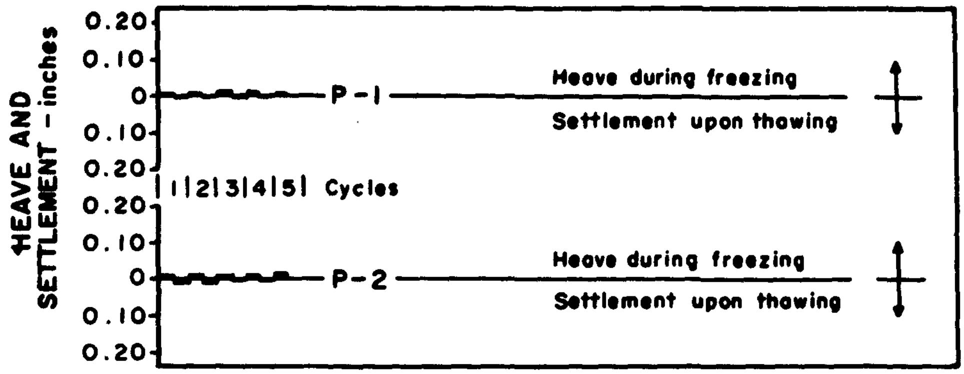


Figure 4. Heave and settlement vs freeze-thaw cycles for Group A.

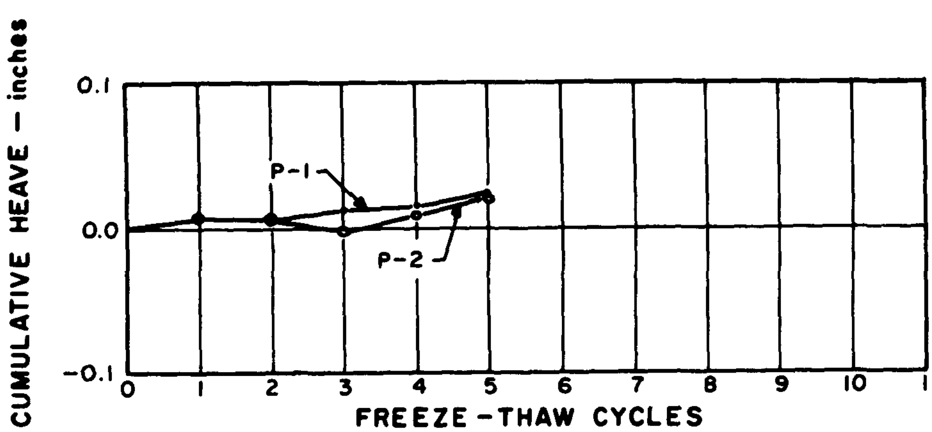


Figure 5. Cumulative heave vs time and freeze-thaw cycles for Group A.

Note: Group A method of cure — Specimens placed in metal container, sealed and placed in oven at 140F for 7 days.

Table 4. Freezing test data for slag-fly ash-lime base-course mixture.

ACFEL specimen no.	Total curing time (weeks)	No. of freeze cycles	Water content - % dry weight			Moisture* change (%)	Initial height (in.)	Final height (in.)	Total cumulative heave (%)
			After curing	After saturation	After freezing test				
P-1	1	5	10.2	15.8	14.9	-5.7	5.90	5.93	0.5
P-2	1	5	10.0	15.7	15.3	-2.5	5.90	5.94	0.7
P-9	6	6	15.3	16.6	17.3	4.2	5.99	6.40	7.0
P-10	6	5	15.6	16.7	18.2	9.0	6.01	6.41	6.7
P-11	15	6	16.0	16.5	16.8	1.8	5.99	6.10	1.9
P-12	15	10	16.0	16.5	18.3	10.9	6.01	6.25	4.0
P-13	54	10	16.4	16.9	15.1	-10.7	6.00	6.12	2.0
P-14	54	6	16.2	17.2	16.2	-5.8	6.03	6.05	0.3
P-15	6	6	15.7	17.5	20.0	14.3	6.11	6.65	8.8
P-16	6	6	14.4	17.6	21.0	19.3	6.15	6.69	8.8
P-17	15	10	17.6	17.6	20.2	14.8	6.12	6.52	6.5
P-18	15	6	17.5	17.6	19.0	8.0	6.12	6.40	4.6
P-19	54	6	17.8	17.8	19.5	9.6	6.14	6.51	6.0
P-20	54	10	17.5	17.5	19.6	10.2	6.11	6.63	8.5
P-21	-	1	no curing	16.1	23.1	43.4	5.94	7.06	18.9
P-22	-	1	no curing	16.0	21.1	31.8	5.93	6.84	13.3

*Based on ratio of weight of moisture gained to initial weight of water in specimen before freezing.

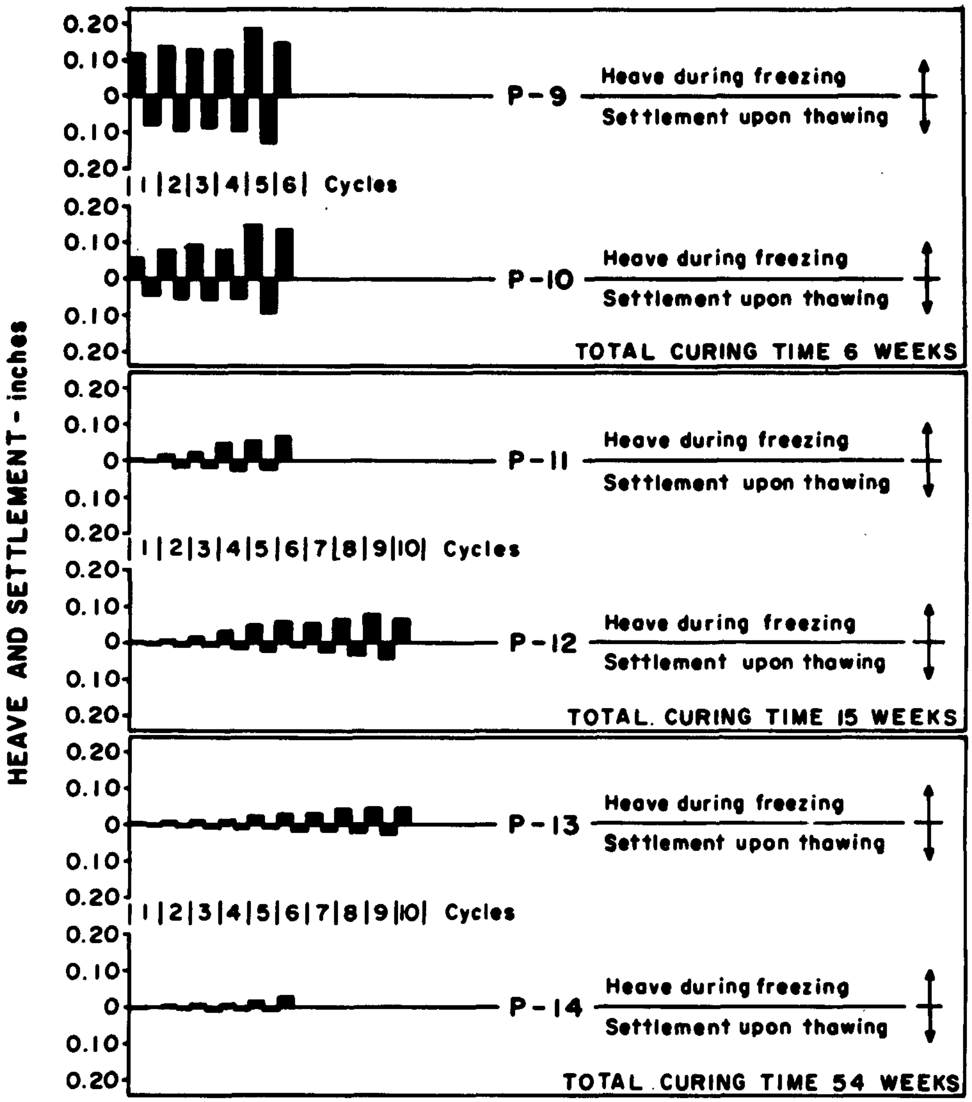


Figure 6. Heave and settlement vs freeze-thaw cycles for Group B.

Note: Group B method of cure — Specimens buried in moist sand, top exposed to room temperature and humidity for two weeks; top covered and curing continued for total period as indicated above.

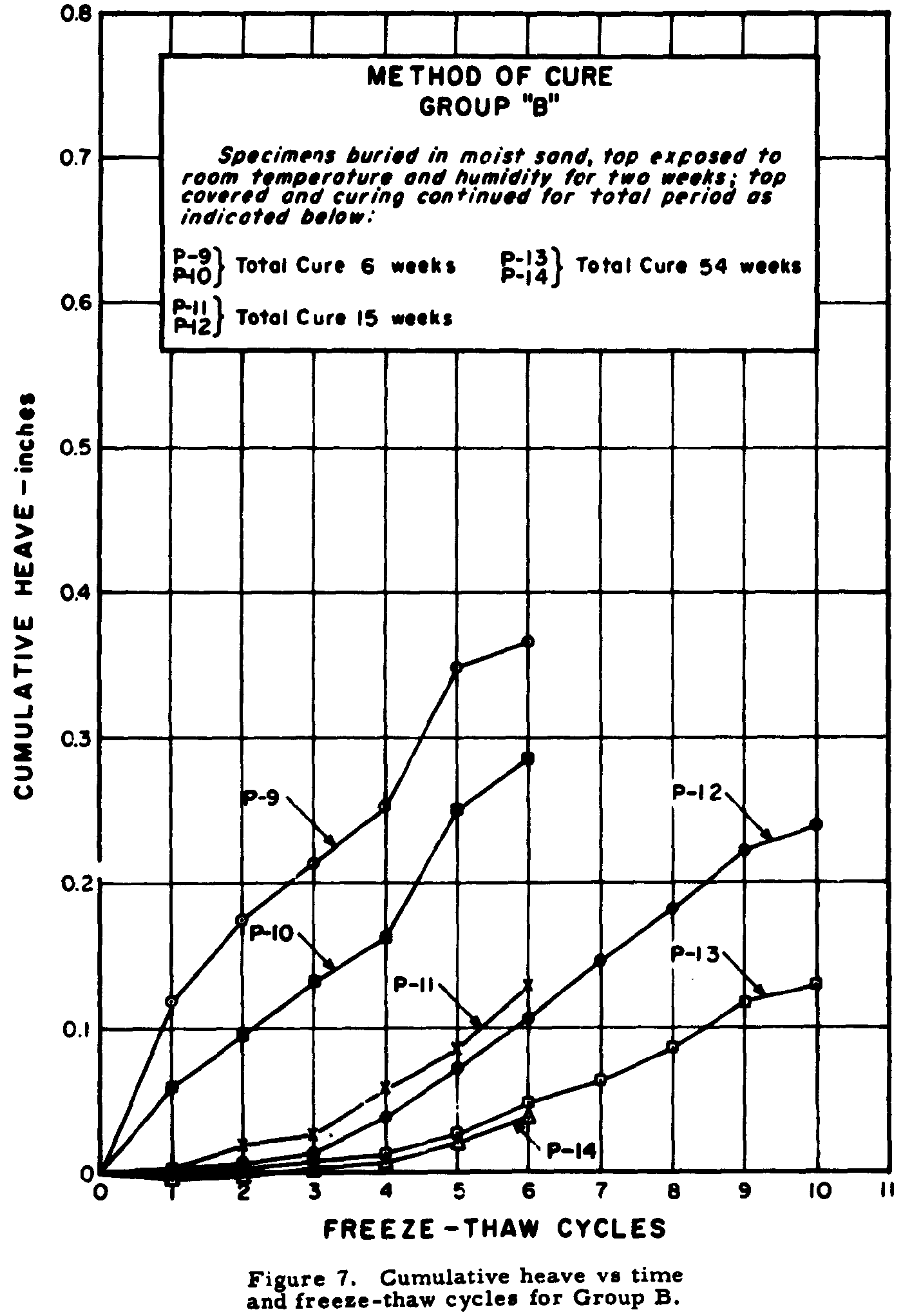


Figure 7. Cumulative heave vs time and freeze-thaw cycles for Group B.

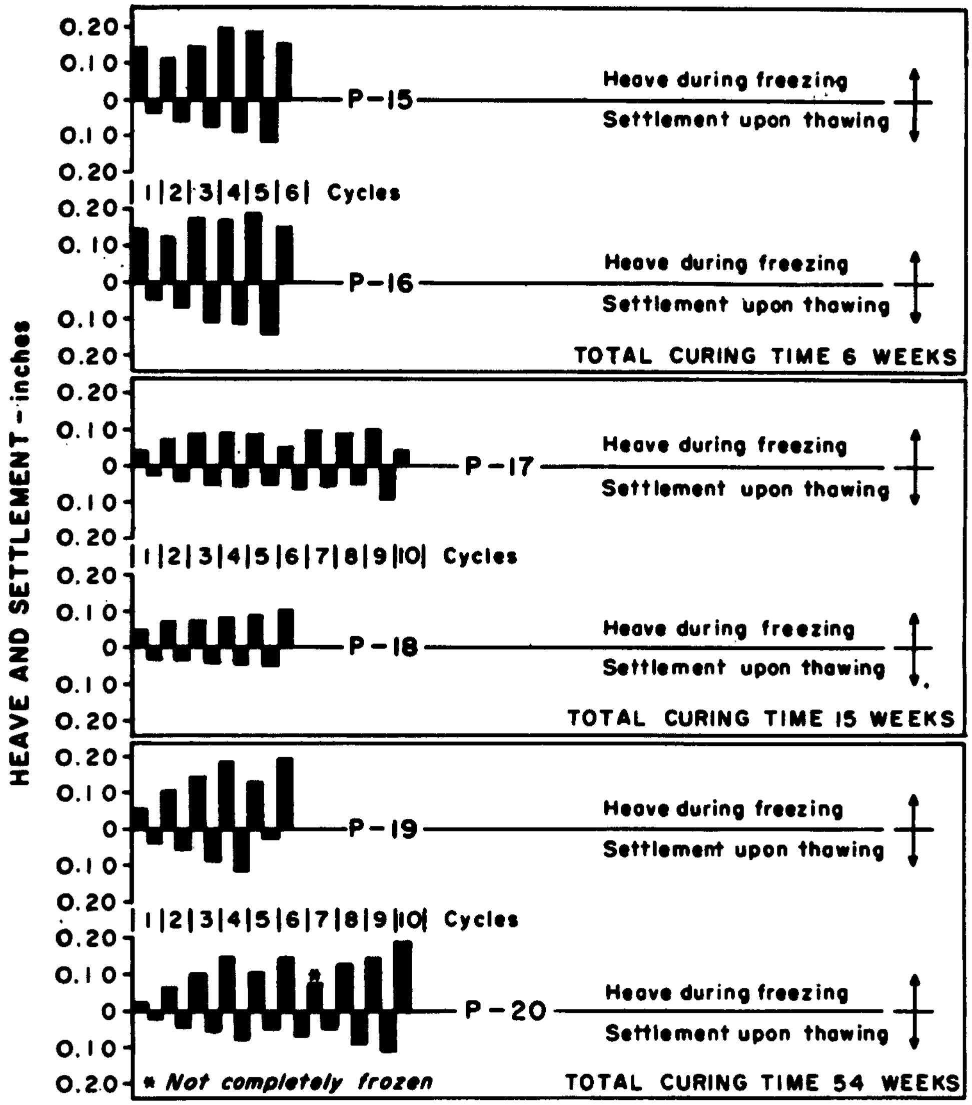


Figure 8. Heave and settlement vs freeze-thaw cycles for Group C.

Note: Group C method of cure — Specimens buried in moist sand for three days, top exposed to room temperature and humidity; then submerged in water for two weeks followed by curing in moist sand for total period indicated above.

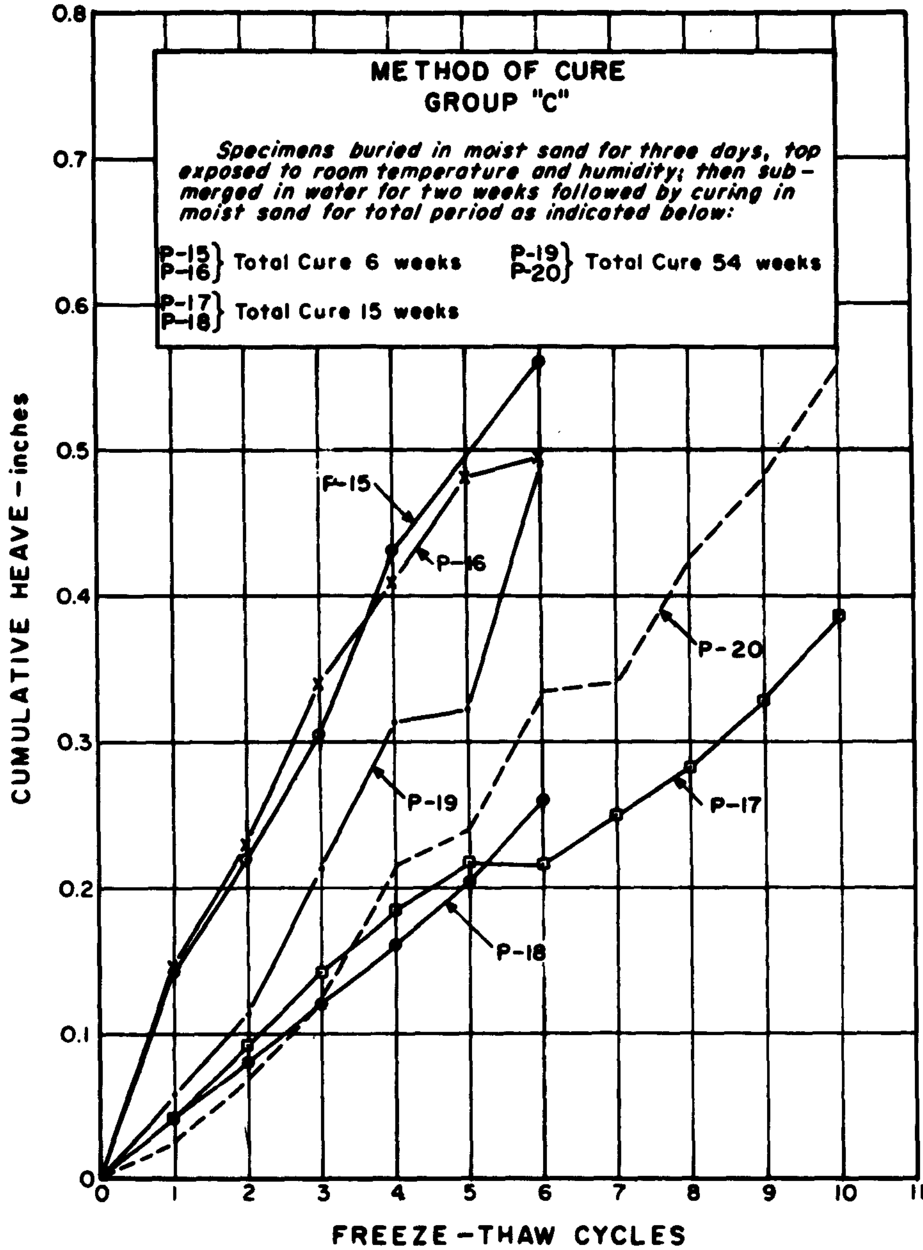
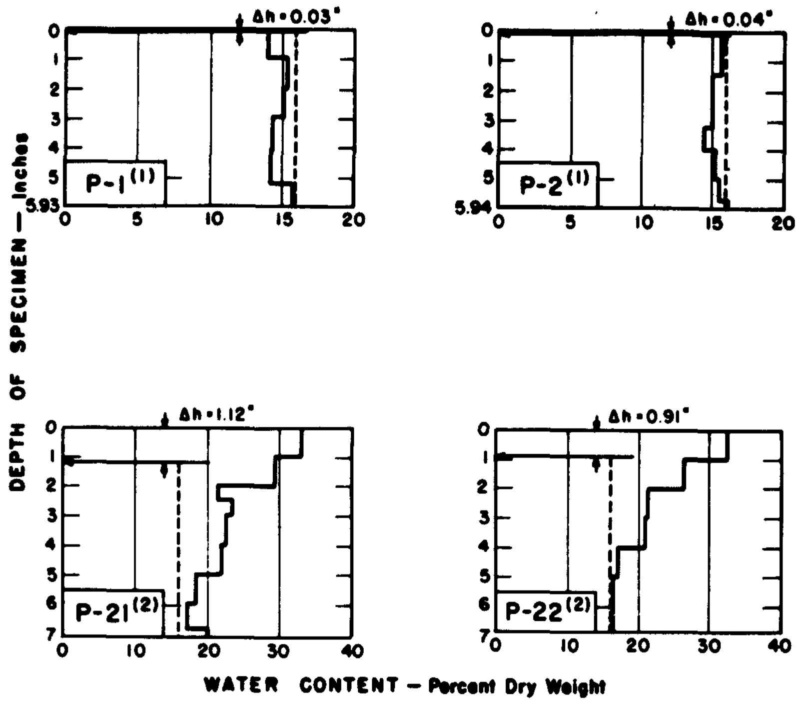


Figure 9. Cumulative heave vs time and freeze-thaw cycles for Group C.



LEGEND:

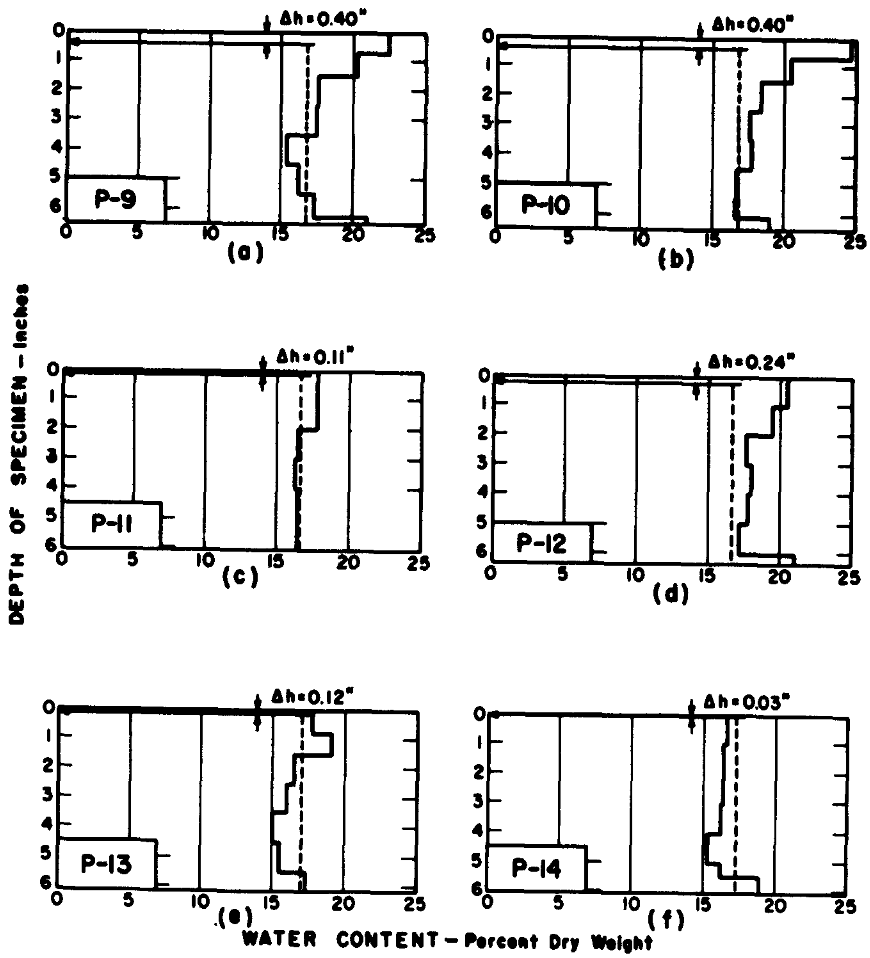
- ----- *Average Original Water Content*
- —— *Water Content After Freezing*
- •—— *Original Height of Specimen before Initial Freezing*
- Δh *Increment of Cumulative Heave*

NOTES:

(1) Group "A". Method of Cure: *Placed in metal container, sealed, and placed in oven at 140° F for 7 days.*

(2) Group "D". *Non-Cured.*

Figure 10. Water content distribution in specimens after final freezing, Groups A and D.



LEGEND:

----- *Average Original Water Content*

—— *Water Content After Freezing*

←— *Original Height of Specimen before Initial Freezing*

Δh *Increment of Cumulative Heave*

NOTE: Group "B" Method of Cure

Specimens buried in moist sand, top exposed to room temperature and humidity for two weeks; top covered and curing continued.

Figure 11. Water content distribution in specimens after final freezing, Group B.

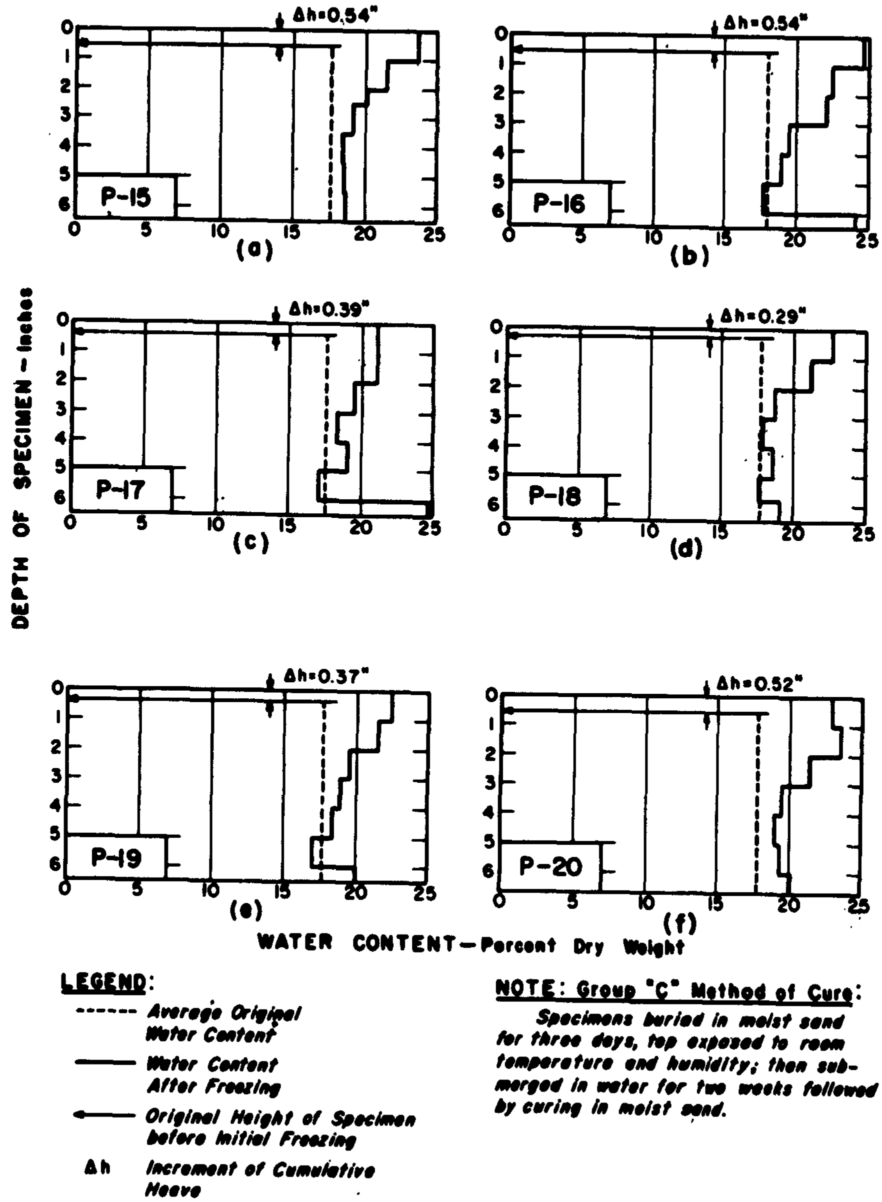


Figure 12. Water content distribution in specimens after final freezing, Group C.

Average rates of heave were computed for all freeze cycles of each specimen. Since the heave plots were not uniform the average maximum rates of heave were also computed, generally for a 3- or 4-day period but never less than for a consecutive 2-day period. The computed heave rates are plotted in Figure 14. It can be readily seen that the heaving of the soaked specimens, P-15 through P-20, was much more pronounced than that of the moist-cured specimens of Group B with the exception of specimens P-9 and P-10, which were cured for only 6 weeks. It will also be noted in this figure that both the average maximum and average heave rates tend to increase slightly with succeeding freeze cycles. Except for P-16 and P-19, both curves remained below the critical 1.0 mm/day dividing line at which the frost-susceptibility classification of a material changes from very low to low. However, the average maximum heave rate in specimen P-9 also came very close to this dividing line at one point. In these tests, because of the apparent frictional restraint developed in the test cylinders by the swelling of the material during curing and probable lateral expansion during freezing, the author believes that the average maximum rates of heave are more truly indicative of the potential frost behavior of this material under adverse conditions of freezing than the average rates of heave.

From the data presented in Figures 6 and 8 it can be observed that, in general, the magnitude of heaving tends to increase slightly with each succeeding cycle. Whether this would be true in a pavement where traffic would tend to densify the thawed material is not known. It appears reasonable to assume that the amount of thaw-settlement in an active pavement would be greater after each thaw because of the traffic loads and that subsequent heaving might also be less because of the sustained high density of the material. In the laboratory tests settlement was influenced only by the overlying weight of material and a static surface load of 0.5 psi.

Examination of data from specimens of group B and C (Fig. 6-9) shows that specimens not soaked in water after preparation reacted more favorably to freezing than those soaked for 2 weeks. For the non-soaked specimens, P-9 through P-12, resistance to heaving was substantially improved with duration of curing time. However, specimens that were moist-cured for only 6 weeks (P-9 and P-10) did not behave substantially better than those that were soaked (P-15 through P-20). Nevertheless, considerable improvement can be observed for the two specimens which were moist-cured 4 months prior to freezing. Specimens moist-cured for 1 yr (P-13 and P-14) show a significant reduction in frost heaving even after 10 repeated freezings. It then appears that curing conditions and duration of curing before freezing exert a considerable influence on subsequent behavior during freezing under adverse conditions of moisture availability.

Figure 15 shows a summary plot relating total cumulative heave versus freeze-thaw cycles and curing time for all specimens used in this investigation.

An inspection of the water content data in Figures 10, 11 and 12 and data in Table 4 show that except for the oven-cured specimens, P-1 and P-2, and P-13 and P-14, all specimens indicated some gain of moisture during the tests. The most substantial moisture gain was evident in the "noncured" specimens P-21 and P-22.

It can be observed in photographs, Figure 13, that some disintegration had begun in the top portions of some of the specimens especially those which were submerged in water as part of curing treatment. A description of each specimen after final freeze, based on visual observations, is presented in Table 5. More disintegration and incipient disintegration was found in the soaked specimens of group C than in those of group B.

CONCLUSIONS AND RECOMMENDATIONS

From the data available from these tests, several significant conclusions are obvious:

1. The mixture of slag-fly ash-lime as used in these tests is classified as low frost-susceptible but approaching medium if subjected to freezing temperatures before it has been adequately cured.

2. For moist-cured specimens (group B) resistance to frost action was improved by increase in curing time (see Fig. 15). What the minimum time for curing should be has not been established by these studies. The available data show that for specimens cured in moist sand, resistance to heaving improved with increase in curing time at least beyond 15 weeks. It is possible that optimum curing time occurs nearer the 15-week period than the 54-week period and less than 15 weeks may be adequate.

In the use of this material as a base course in a roadway, it is important that it be placed sufficiently early in the season to permit adequate curing before onset of freezing weather.

3. Specimens which were soaked (group C) prior to curing in moist sand showed less resistance to frost action than non-soaked specimens (group B). This is indicated by the heave data presented in Figures 6 through 9, the computed average maximum and average rates of heave shown in Figure 14, and the physical appearance of specimens after freezing as described in Table 5. It is also noteworthy that resistance to heaving was not significantly improved with increase of curing time after soaking, as was observed for the non-soaked specimens. In fact, heaving characteristics after 1 yr of curing were very similar to those exhibited after 6 weeks of curing.

In field practice it appears that it would be advantageous to protect this material soon after placing from being soaked or inundated.

It should be emphasized that the computed average heave rate in these tests (over a consecutive period of 5 days or more) in no instance exceeded 1.0 mm/day except for the two noncured specimens. However, the average maximum rate of heave over a consecutive period of generally 2 to 4 days exceeded 1.0 mm/day in specimens P-16 and P-19 during one of their respective freeze periods.

It has been ACFEL's experience that base-course specimens which heave in the laboratory freezing tests at an average rate of heave exceeding 1.0 mm/day are likely to show undesirable heaving in the field, and subsequent weakening characteristics when adverse conditions of water availability and temperature are present. The author further wishes to emphasize here that the laboratory freezing tests simulate extremely severe field conditions in which an unlimited supply of water is available to the base course during the freezing process. Such a condition is seldom present in a well-designed roadway where adequate drainage has been provided. Therefore, the test results obtained in the laboratory during freezing are unlikely to be duplicated in severity under most normal field conditions.

It is recognized that the test data presented in this paper do not provide answers to all the questions that might be asked relative to frost-heaving characteristics of slag-fly ash-lime base-course mixtures. Much more study and experimentation can be done in this area, particularly to determine minimum standards of field-curing treatment and time of field placement to insure the most favorable resistance to possible effects of freezing. Freezing effects on different mix proportions and on mixes containing other types of aggregate and having different densities could be studied. No evaluation of frost susceptibility can be complete without methodical observation of field behavior of slag-fly ash-lime base courses placed in unfavorable areas under unfavorable climatic conditions. Further study in all the above indicated areas would provide data of considerable interest and shed more light on the frost behavior characteristics of artificial pozzolanic mixtures.

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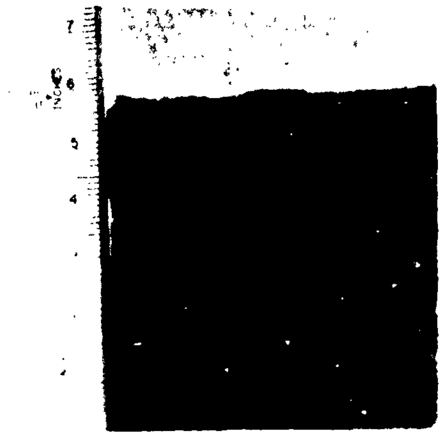
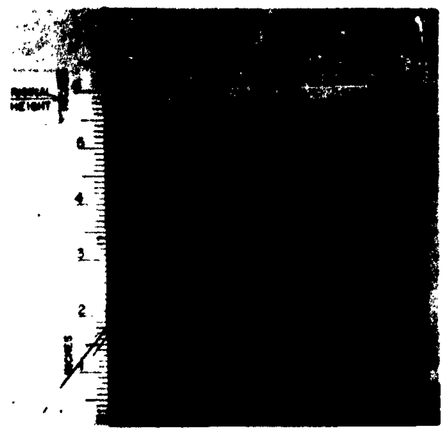


Specimen P-1. Cured 7 days at 140F. After 5th freeze. Horizontal grooves at left show locations of thermocouple wires.

(a)

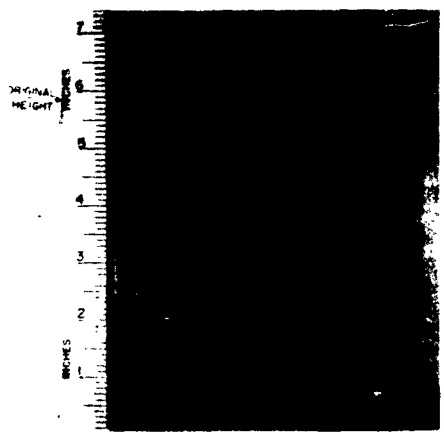


Specimen P-2. Cured 7 days at 140F. After 5th freeze.

(b)

Specimen P-21. Noncured. After one slow freeze ($\frac{1}{4}$-in. per day).

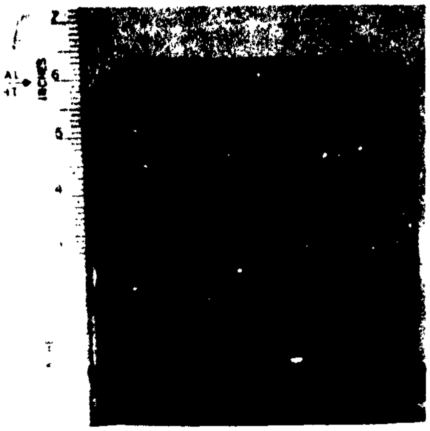
(c)



Specimen P-22. Noncured. After one slow freeze ($\frac{1}{4}$-in. per day). Thermocouple grooves at right.

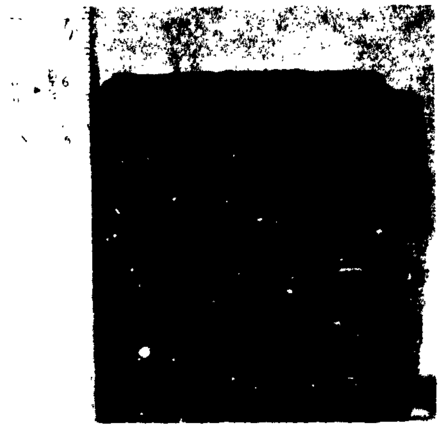
(d)

Figure 13. Photographs of vertical sections of frozen specimens of a slag-fly ash-lime mixture.



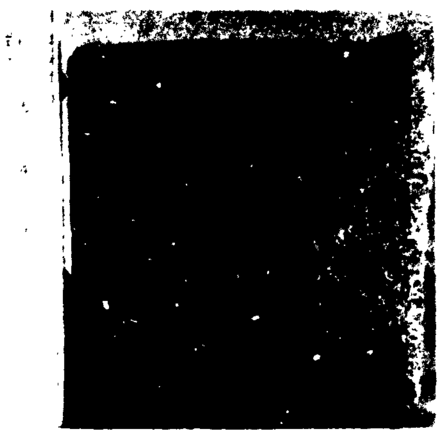
Specimen P-9. Cured 6 weeks in moist sand. After 6th freeze.

(e)



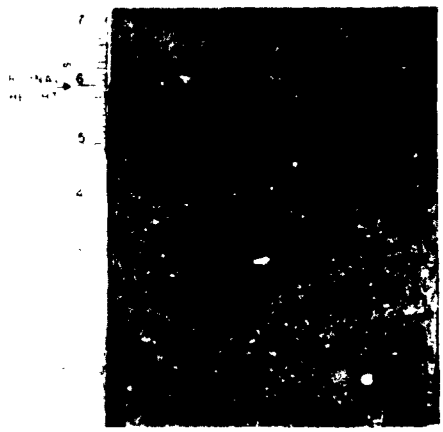
Specimen P-10. Cured 6 weeks in moist sand. After 5th freeze. Thermocouple grooves at right.

(f)



Specimen P-11. Cured 15 weeks in moist sand. After 6th freeze.

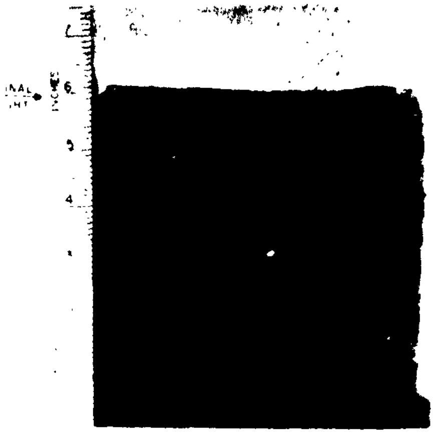
(g)



Specimen P-12. Cured 15 weeks in moist sand. After 10th freeze. Thermocouple grooves at right.

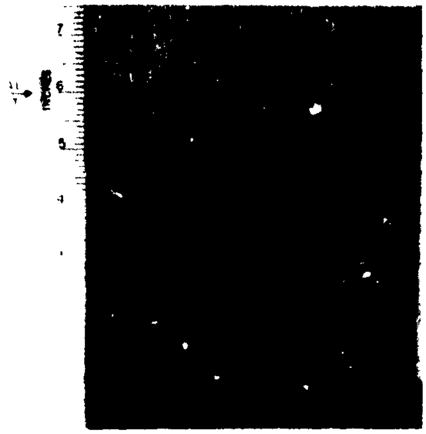
(h)

Figure 13. (Cont'd) Photographs of vertical sections of frozen specimens of a slag-fly ash-lime mixture.



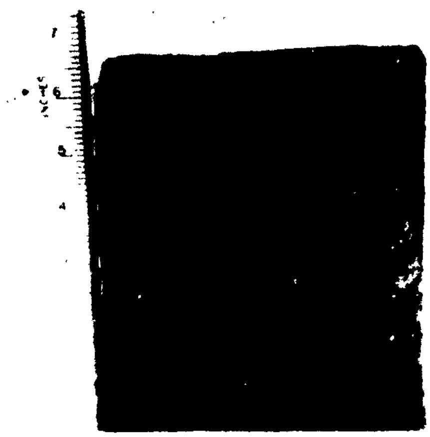
Specimen P-13. Cured 54 weeks in moist sand. After 10th freeze. Thermocouple grooves at right.

(i)



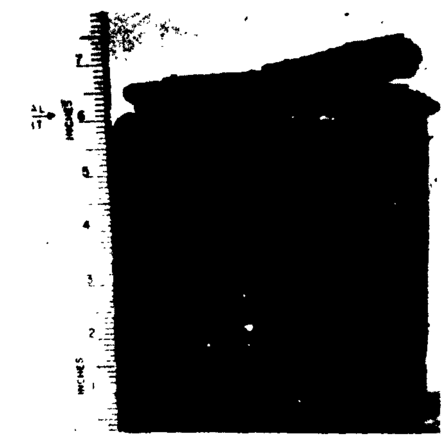
Specimen P-14. Cured 54 weeks in moist sand. After 6th freeze.

(j)



Specimen P-15. Cured submerged for 2 weeks and 4 weeks in moist sand. After 6th freeze.

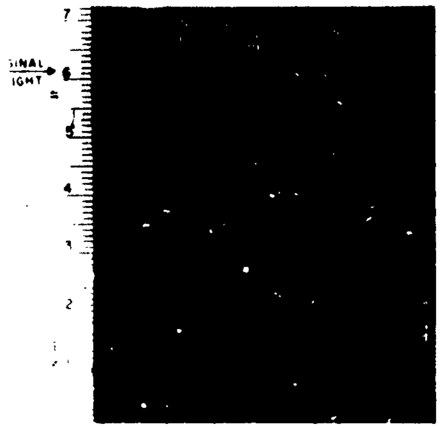
(k)



Specimen P-16. Cured submerged for 2 weeks and 4 weeks in moist sand. After 6th freeze.

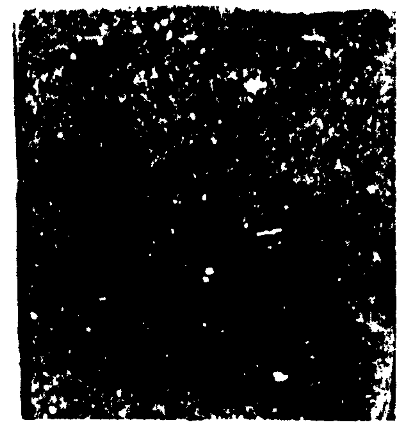
(l)

Figure 13. (Cont'd) Photographs of vertical sections of frozen specimens of a slag-fly ash-lime mixture.



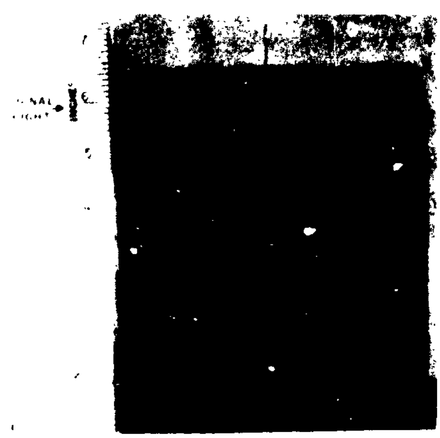
Specimen P-17. Cured submerged 2 weeks and 13 weeks in moist sand. After 10th freeze. Thermocouple grooves at right.

(m)



Specimen P-18. Cured submerged 2 weeks and 13 weeks in moist sand. After 6th freeze.

(n)



Specimen P-19. Cured submerged 2 weeks and 52 weeks in moist sand. After 6th freeze.

(o)

Specimen P-20. Cured submerged 2 weeks and 52 weeks in moist sand. After 10th freeze. Thermocouple grooves at left.

(p)

Figure 13. (Cont'd) Photographs of vertical sections of frozen specimens of a slag-fly ash-lime mixture.

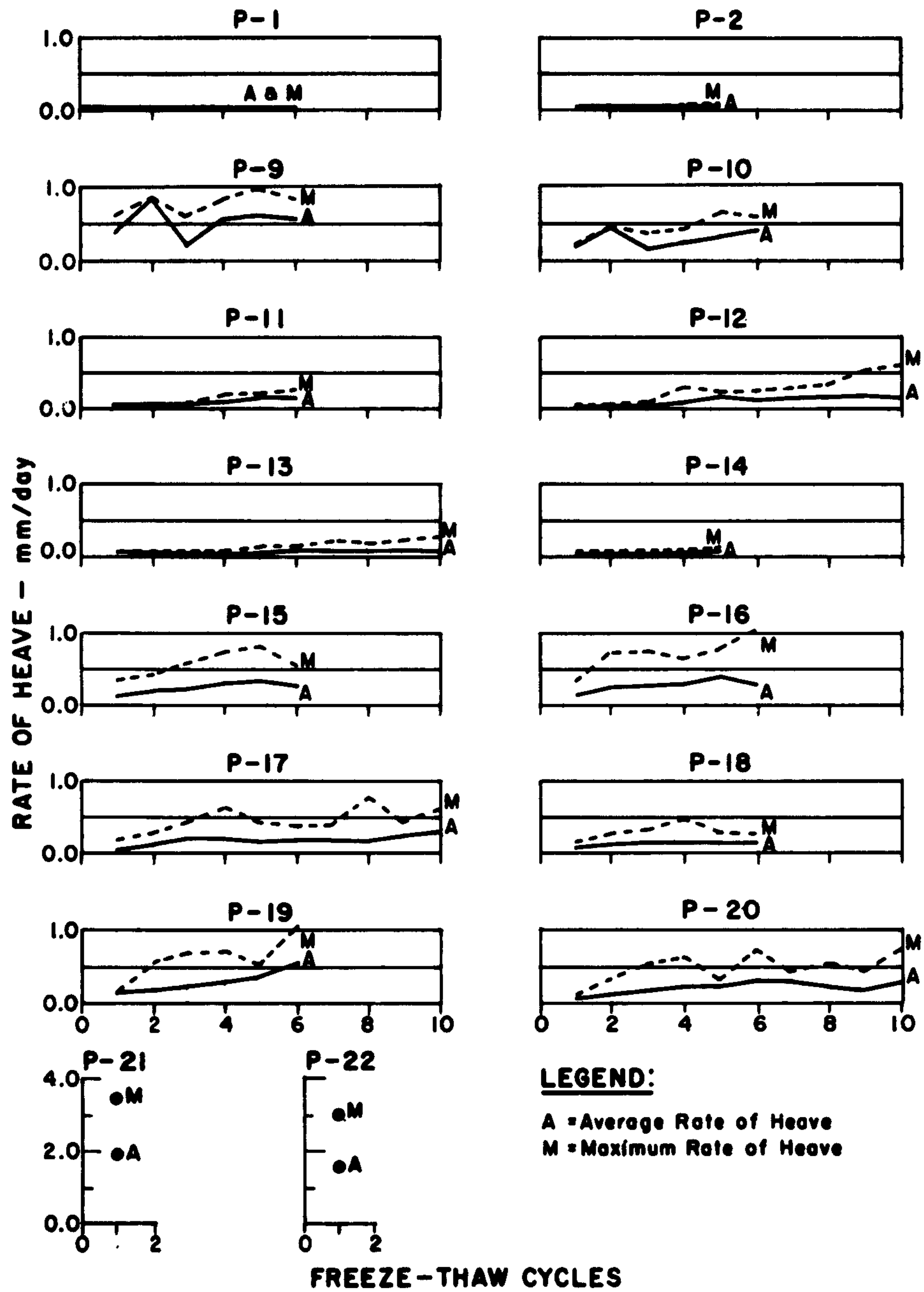


Figure 14. Rate of heave vs freeze-thaw cycles.

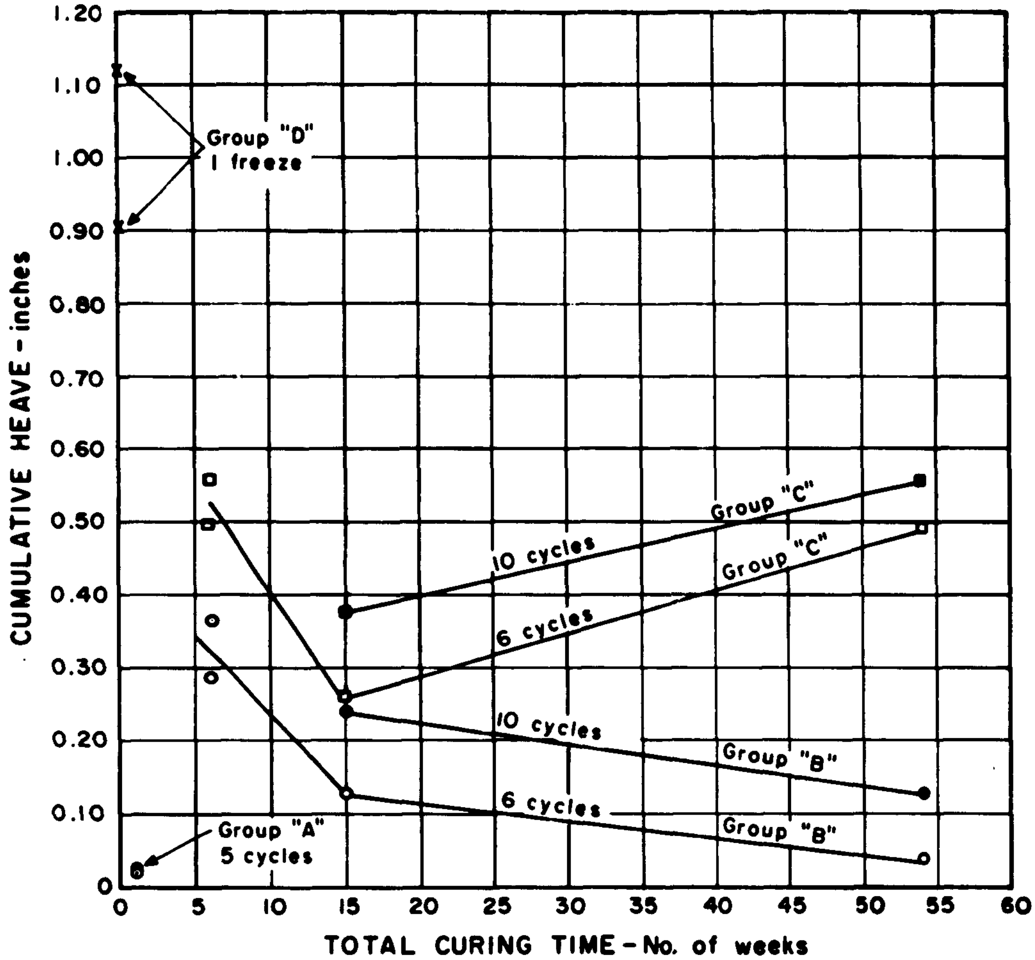


Figure 15. Summary of cumulative heave vs curing time and freeze-thaw cycles.

TABLE 5

VISUAL OBSERVATIONS OF FROZEN SPECIMEN AFTER COMPLETION OF FREEZING TESTS

ACFEL Specimen Number	Location Distance from Top (inches)	Description of Ice Phase	Approximate Thickness of Segregated Ice (inches)	Approximate Spacing Between Segregated Ice (inches)	Other Data and Observations
P-1	0 to bottom	no visible ice lenses	-	-	No visible ice lenses. Material was hard like concrete after oven drying.
P-2	0 to bottom	no visible ice lenses	-	-	No visible ice lenses. Material was hard like concrete after oven drying.
P-9	0 to 1-1/2	ice lenses	hairline	1/32 to 1/16	Specimen not completely frozen.
	1-1/2 to 3-1/2	ice lenses	very fine	1/8 to 1/4	
	3-1/2 to 6-1/4	ice lenses	very fine	scattered	
	6-1/4 to bottom	unfrozen	-	-	
P-10	0 to 1-1/2	ice lenses	very fine to hairline	1/32 to 1/16	
	1-1/2 to 2-1/2	ice lenses	hairline	1/4 to 1/2	
	2-1/2 to 6-1/8	ice lenses	very fine	scattered	
	6-1/8	ice lens	hairline	-	
	6-1/8 to bottom	no visible ice lenses		-	
P-11	0 to 1	ice lenses	very fine to hairline	1/16 to 1/8	Some disintegration observed in top 1/2-inch.
	1 to 3	ice lenses	very fine	1/8 to 1/4	
	3 to bottom	no visible ice lenses	-	-	
P-12	0 to 1	ice lenses	very fine to hairline	1/32 to 1/16	Some disintegration observed in top 1/2-inch.
	1 to 2	ice lenses	very fine	1/4 to 1/8	
	2 to bottom	no visible ice lenses	-	-	
P-13	0 to 1-1/2	ice lenses	very fine to 1/64	1/8 to 1/4	Top 3/4-inch shows sharp separation of several layers due to ice lensing.
	1-1/2 to 2-1/2	ice lenses	very fine to hairline	1/4 to 1/2	
	2-1/2 to bottom	ice lenses	very fine	scattered	
P-14	0 to 2	ice lenses	very, very fine	1/16 to 1/8	Evidence of separation of 1/4-inch thick layer visible at top of specimen.
	2 to 5	no visible ice lenses			
	5 to 5-1/2	ice lenses	very, very fine	1/8	
	5-1/2 to bottom	no visible ice lenses			

TABLE 5 (Continued)

VISUAL OBSERVATIONS OF FROZEN SPECIMEN AFTER COMPLETION OF FREEZING TESTS

ACFEL Specimen Number	Location Distance from Top (inches)	Description of Ice Phase	Approximate Thickness of Segregated Ice (inches)	Approximate Spacing Between Segregated Ice (inches)	Other Data and Observations
P-15	0 to 2-1/2	ice lenses	very fine to hairline	1/64 to 1/4	Specimen somewhat dried around circumferential area of top portion. Horizontal cracks visible in top inch of specimen.
	2-1/2 to bottom	ice lenses	fine (short)	scattered	
P-16	0 to 4	ice lenses	very fine to hairline	1/8 to 1/4	Severe layered disintegration in top 1-1/2 inches.
	4 to bottom	ice lenses	fine (short)	scattered	
P-17	0 to 2	ice lenses	hairline	1/32 to 1/16	Slightly dried around circumferential area of top portion. Incipient and visible layered separation on top 3/4-inch.
	2 to 3	ice lenses	very fine	1/8 to 1/4	
	3 to bottom	ice lenses	very, very fine	scattered	
P-18	0 to 1	ice lenses	very fine to hairline	1/16 to 1/8	Incipient and visible layered separation on top 3/4-inch.
	1 to 3	ice lenses	very fine	1/8 to 1/4	
	3 to bottom	ice lenses	very fine	scattered	
P-19	0 to 2	ice lenses	very fine to hairline	1/4	Specimen slightly dried around circumferential area of top portion. Considerable disintegration in top 3/4 inch and incipient disintegration in next 3/4-inch.
	2 to 3	ice lenses	very fine to hairline	1/8 to 1/4	
	3 to 5	ice lenses	very fine to hairline	1/4	
	5 to bottom	ice lenses	very fine to hairline	scattered	
P-20	0 to 2	ice lenses	very fine to hairline	1/32 to 5/32	Specimen slightly dried around circumferential area of top portion. Considerable incipient spalling visible in top 1-1/4 inches.
	2 to bottom	ice lenses	very fine	scattered	
P-21	0 to 2	ice lenses	very fine to hairline	1/32 to 1/16	Slightly dried around circumferential area of top portion. Specimen soft upon thawing. Crumbled easily after oven drying.
	2 to 2-1/2	ice lenses	very fine	1/16 to 1/4	
	2-1/2 to 3	ice lenses	very, very fine	scattered	
	3 to bottom	no visible ice lenses			
P-22	0 to 1	ice lenses	very, very fine	1/16	Slightly dried around circumferential area of top portion. Specimen soft upon thawing. Crumbled easily after oven drying.
	1 to bottom	no visible ice lenses			

AD Accession No.

U. S. Army Cold Regions Research and Engineering Laboratory, Army Materiel Command, Hanover, N.H.
LABORATORY EVALUATION OF FROST HEAVE CHARACTERISTICS OF A SLAG-FLY ASH-LIME BASE-COURSE MIXTURE — Chester W. Kaplar

Technical Report 96, Jan 1963, 28p-illus.-tables.
Military Construction Investigations Program

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